Appendix 13

TOP-DOWN COMMERCIAL EVALUATION OF CFB

APPENDIX 13 – CIRCULATING FLUIDIZED BED COMBUSTION

A top-down analysis of Circulating Fluidized Bed (CFB) technology was conducted to evaluate the technology against that of the WPES. The analysis takes a five step approach: (1) describe the technology, (2) eliminate the technology from further analysis if it is determined to be infeasible, (3) rank the technologies according to control effectiveness, (4) analyze the economic, energy, and additional environmental impacts of the technologies, and (5) select the most appropriate technology based on the determinations of steps 3 and 4.

Step 1 - Control Technology Description

CFB combustion is a process for the combustion of solid fuel in which the fuel is held in suspension in a bed primarily consisting of fuel, fuel ash, limestone, and other inert materials. CFB boiler technology has been successfully applied to the process industries and the electric power industry, although its application is limited by the smaller steam generating capacity that can be produced by a single boiler relative to a PC boiler. A CFB boiler can inherently produce less NO_x and SO_2 emissions than a PC boiler without add-on controls; however, to achieve the currently required emissions levels, both CFB and PC boilers require add-on controls removing the emissions advantage of CFB. The CFB boiler continues to hold an advantage over the PC boiler with respect to its ability to burn lower quality fuels.

Technology

A CFB boiler combusts fuel while it is in a dense bed of material consisting of fuel, fuel ash, limestone, and other inert bed materials. The bed is supported within the furnace by air flowing into the bed from the bottom of the furnace. The air flow supports the bed and promotes mixing of the fuel and air to provide complete combustion. The bed temperature is typically below 2,000°F, which maintains the fuel ash below the softening point and also reduces the formation of thermal NO_x. The bed is sized to achieve low gas velocities that allow for long fuel residence time in the furnace which helps complete combustion and maximize heat transfer to the water-cooled furnace walls. Simultaneous with the fuel combustion, limestone reacts with SO_2 formed during combustion to lower overall SO_2 emissions from the boiler.

The intimate mixing of air and fuel, low combustion temperature, long residence time, and in-situ removal of SO_2 make CFB technology an ideal system for the combustion of fuels with low volatile matter content (such as anthracite coals and pet coke), high ash content (such as waste coal), and high sulfur content. Additionally, a CFB boiler has greater fuel flexibility relative to a PC boiler, which gives an owner the ability to minimize fuel expenses by burning lower quality, lower cost fuels.

History

Fluidized bed technology development was initiated in the 1920's as a process for the refining of petroleum and the production of chemical feedstocks from coal. Until the 1960's, fluidized bed technology was focused on the process industries. In the 1960's, governments (particularly in the U.S. and England) began looking at fluidized bed technology as a means to utilize coal while reducing emissions of SO_2 and NO_x. At that time, governments and boiler manufacturers began investing in the development of the technology and began building test modules and small scale commercial boilers. With the progression of time, a greater understanding of the CFB technology was gained which enabled boiler manufacturers to offer larger CFB boilers and expand the potential range of application from small industrial boilers to larger utility boilers.

The CFB combustion process is now a mature technology and CFB boilers have gained acceptance as a steam generator technology for power generation. Table 13.1 summarizes some of the most recent domestic applications of CFB boilers for power generation.

Table 13.1 – Recent Domestic CFB Boiler Applications for Power Generation

Plant	**Location**	**Operation**	**Capacity MW (gross)**	**Fuel**
Tractebel Red Hills	Mississippi	2001	2 x 250 MW	Lignite
JEA Northside	Florida	2001	2 x 300 MW	Coal, pet coke
AES Puerto Rico	Puerto Rico	2002	2 x 250 MW	Coal
Reliant Seward	Pennsylvania	2004	2 x 292 MW	Waste coal
East Kentucky Power Coop	Kentucky	2004	1 x 268 MW	Coal

Performance

In terms of combustion performance, a CFB boiler has a marginally higher combustion efficiency relative to a PC boiler. This higher efficiency is gained from less unburned carbon due to the longer furnace residence time and the ability to lower the air heater exit temperature due to the lower concentration of SO_3 in the flue gas. However, the overall efficiency of a facility with a CFB boiler and FGD system will be lower relative to a facility with a PC boiler, SCR, and FGD system due to the higher auxiliary power consumption of the CFB boiler auxiliaries. The result of this lower efficiency is a higher fuel consumption rate for an equivalent electric generating capacity.

CFB units have a more restrictive ramp rate than PC boilers because of the considerable mass of material in the bed that needs to be moved and kept within temperature ranges. CFB units can operate at baseload and in a load-following mode. The load-following capability is limited in comparison to PC boilers. Minimum load is in the 40% range, without supplemental fuel. CFB technology is not well suited for on-off cycling. The bed material is susceptible to hardening if the bed temperature falls below its recommended operating range.[1]

The amount of combustion products generated by a facility equipped with a CFB boiler and a dry FGD system will be higher than a facility equipped with a PC boiler and a dry FGD system as a result of the overall lower efficiency of the CFB boiler based facility and the higher limestone consumption of a CFB boiler relative to the lime consumption of a PC boiler equipped with a dry FGD system. Table 13.2 below shows a comparison of the fuel and reagents consumed by each technology and by-products generated for a 1,590 MW facility firing PRB coals.

Table 13.2 – Comparison of Fuel Consumption and Combustion Product Generation

	CFB Boilers	**PC Boiler**

[1] Sargent & Lundy, LLC, "New Coal Generation Technology Assessment Study." November 2005

Fuel consumption (tpy)	8,540,285	8,359,116
Incremental fuel consumption (tpy)	181,169	--
Fuel ash (tpy)	439,824	423,204
Sulfur absorption products (tpy)	312,300	170,593
Incremental disposal volume (tpy)	158,327	--

Step 2 - Eliminate Technically Infeasible Options

CFB technology is typically used with local low rank fuel supplies. Thus it has not been field-proven whether there would be operational issues with fine coal particles of PRB being carried over from the furnace section through the cyclone section into the back pass area. PRB coal dust is more prone to self-ignition than other coals, thus fine coal particles of PRB in the back pass area would create a potential fire hazard. However, CFB technology has commercial experience and is a reliable source of coal electric generation. Therefore, CFB is considered technically feasible.

Step 3 - Rank Control Technologies

Other than the ability to burn fuels not typically suitable for a PC boiler, the main advantage of a CFB boiler is the lower emission of NO_x and SO_2 relative to a PC boiler not equipped with selective catalytic reduction (SCR) or flue gas desulfurization (FGD). The lower combustion temperature of a CFB boiler will generate less thermal NO_x while SO_2 emissions are reduced by the reaction with limestone in the bed.

Recent facilities equipped with CFB boilers have used post-combustion controls to further reduce emissions of NO_x and SO_2 to meet the increasingly stringent emissions requirements. The controls typically applied are selective noncatalytic reduction systems (SNCR) to reduce NO_x emissions and dry FGD systems to reduce SO_2 emissions. An SNCR reduces NO_x by injecting urea or ammonia into the furnace which reacts with NO_x to form N_2, O_2, and H_2O. A dry FGD system may use bed material collected in a baghouse as the reagent or fresh lime feed similar to a dry FGD system installed with a PC boiler. The utilization of bed material or lime as the reagent in the dry FGD system is an economic decision based on the amount of additional SO_2 reduction required and the relative costs of limestone and lime.

Similar to recent CFB boiler installations, a new PC boiler will be required to install post-combustion controls to reduce emissions of NO_x and SO_2. The systems typically installed are SCR for control of NO_x emissions and FGD for control of SO_2 emissions. The addition of these systems enables a PC boiler facility to have emissions equal to the emissions from a facility equipped with a CFB boiler, SNCR, and dry FGD system.

SO_2

The projects listed in Table 13.3 represent CFB coal-fired facilities burning coal only. Most CFB units are designed to burn waste or low rank coal that is typically high in sulfur. Therefore, many of the CFB permits have short-term SO_2 emissions limits (in lbs/MMBtu) that are consistently higher than the SO_2 limit of 0.09 lbs/MMBtu proposed for the Facility.

NEVCO Sevier
A permit was recently issued (October 2004) by Utah DAQ to NEVCO to construct a CFB facility that contains a SO_2 emissions rate of 0.022 lb/MMBtu, averaged over 30 days; the 24-hour SO_2 permit rate is 0.05 lb/MMBtu. The NEVCO facility, however, has not been constructed. Therefore these emission rates have not been demonstrated.

AES Puerto Rico
AES Puerto Rico was originally permitted in 2001 with an SO_2 limit of 0.022 lb/MMBtu using limestone injection and a circulating dry scrubber. Based on information obtained from conversations with representatives of AES Puerto Rico, the facility is consistently meeting its permitted SO_2 limit. WPEA has requested documentation from the Puerto Rico Environmental Quality Board showing the demonstrated emissions of the facility, but has not yet been able to confirm the actual emissions.

CFB technology has the ability to greatly reduce SO_2 emissions leaving the boiler. When this technology is combined with the use of low-sulfur coal and a post-combustion circulating dry scrubber, as with AES Puerto Rico, the facility has the potential to significantly reduce SO_2 emissions. However, as is shown in the following section, the AES Puerto Rico facility has higher NO_x emissions than the proposed limit for the Facility.

WPEA is proposing an SO_2 emission rate of 0.09 lb/MMBtu on a 24-hour rolling average basis. A comparison of the WPEA proposed rate and the lowest permitted and demonstrated CFB SO_2 emission rates is presented in Table 13.3.

Table 13.3 - Ranking of SO_2 Emission Rates

Facility	Emissions (lb/MMbtu)	Averaging Period	Plant Type	Notes
NEVCO Energy Company, LLC	0.022	30-day rolling avg	CFB	10/24/04 Permit – Not yet constructed
AES Puerto Rico	0.022	30-day rolling avg	CFB	10/29/2001 Permit
WPEA	0.09	24-hr rolling avg	PC with a dry scrubber	Proposed
AES Beaver Valley	0.14	30-day rolling avg	CFB	11/21/2001 Permit
AES Warrior Run	0.16	30-day rolling avg	CFB	6/30/1994 Permit
JEA Northside	0.2	30-day rolling avg	CFB	7/14/1999 Permit
Energy New Bedford	0.23	30-day rolling avg	CFB	7/11/1994 Permit
Choctaw Generation	0.25	30-day rolling avg	CFB	8/25/1998 Permit

York County	0.25	30-day rolling avg	CFB	7/25/1995 Permit
Archer Daniels Midland – Cedar Rapids	0.36	30-day rolling avg	CFB	6/30/1998 Permit
Archer Daniels Midland – Decatur	0.7	30-day rolling avg	CFB	12/24/1998 Permit

NO_x

As shown in Table 13.4 below, the average NO_x emission rate for a CFB is approximately 0.09 lb/MMBtu, and the lowest emission rate is 0.07 lb/MMBtu, each on a 30-day rolling average basis. The most recent permit issued for a CFB (the Nevco-Sevier Plant in Utah) has an emission rate of 0.10 lb/MMBtu on a 24-hour basis.

WPEA is proposing a NO_x emission rate of 0.07 lb/MMBtu on a 24-hour rolling average basis. A comparison of the WPEA proposed rate and the lowest permitted and demonstrated CFB NO_x emission rates is presented in Table 13.4.

Table 13.4 – Ranking of NO_x Emission Rates

Facility	**Emissions (lb/MMbtu)**	**Averaging Period**	**Plant Type**	**Notes**
WPEA	0.07	24-hr rolling avg	PC with SCR	Proposed
East Kentucky Power Coop	0.07*	30-day rolling avg	CFB	6/21/02 Permit
Kentucky Mountain Power, LLC	0.07	30-day rolling avg	CFB	5/4/01 Permit
ADM Company	0.07	30-day rolling avg	CFB	6/30/98 Permit
River Hill Power Company, LLC	0.07	30-day rolling avg (LAER)	CFB	4/11/06 RBLC
Greene Energy Resource Recovery Project	0.08	30-day rolling avg (LAER)	CFB	4/11/06 RBLC
Gascoyne Generating Station	0.09	30-day rolling avg	CFB	4/11/06 RBLC
Montana-Dakota Utilities – Westmoreland	0.09	30-day rolling avg	CFB	Application
JEA Northside	0.09	30-day rolling avg	CFB	7/14/99 Permit
ADM Company	0.09	30-day rolling avg	CFB	12/24/98 Permit
NEVCO Energy Company, LLC	0.10	24-hr rolling avg	CFB	10/24/04 Permit
Indeck, Elwood	0.10	30-day rolling avg	CFB	10/10/03 Permit
AES Puerto Rico	0.10	30-day rolling avg	CFB	10/29/01 Permit
Northamption Generating Co.	0.10	30-day rolling avg	CFB	4/14/95 Permit
Deseret Generation & Transmission	0.10	30-day rolling avg	CFB	
AES Beaver Valley	0.101	30-day rolling avg	CFB	11/21/01 Permit

* Emission rate is waived during the SNCR optimization study.

PM_{10}

The average PM_{10} emission rates from the listed CFB units was 0.016 and the lowest was 0.0088 lb/MMBtu. The latest issued CFB permit (the Nevco-Sevier Plant in Utah) has an emission rate of 0.0154 lb/MMBtu on a 24-hour basis. These permitted emission rates, along with several others, are shown in Table 13.5.

Northampton Generating Company
Recent stack emissions monitoring of Northampton has shown hourly average PM_{10} emissions to be greater than the permitted limit of 0.0088 lb/MMbtu. In addition, the Northampton facility burns blended fuels comprised of a combination of waste coal, pet coke, paper processing residual and virgin wood chips. These fuels are significantly different than PRB and therefore should not be used as a point of comparison.

A comparison of the WPEA proposed rate and the lowest CFB filterable PM_{10} emission rates is presented in Table 13.5.

Table 13.5 – Ranking of Filterable PM_{10} Emission Rates

Plant Name	Emissions (lb/MMbtu)	Averaging Period	Plant Type	Notes
Northampton Generating Co.	0.0088	3-hour avg	CFB	4/14/95 Permit
River Hill Power Company, LLC	0.01	3-hour avg	CFB	4/11/06 RBLC
JEA Northside	0.011	3-hour avg	CFB	7/14/99 Permit
York County Energy Partners	0.011	3-hour avg	CFB	7/25/95 Permit
Lamar Light & Power Power Plant	0.012	3-hour avg	CFB	4/11/06 RBLC
Greene Energy Resource Recovery Project	0.012	3-hour avg	CFB	4/11/06 RBLC
WPEA	0.015	3-hour avg	PC with fabric filter	
East Kentucky Power Coop	0.015	3-hour avg	CFB	6/21/02 Permit
Kentucky Mountain Power, LLC	0.015	3-hour avg	CFB	3/4/01 Permit
Montana-Dakota Utilities – Westmoreland	0.015	3-hour avg	CFB	Application
Indeck, Elwood	0.015	3-hour avg	CFB	10/10/03 Permit
AES Puerto Rico	0.015	3-hour avg	CFB	10/29/01 Permit
Deseret Generation & Transmission	0.015	3-hour avg	CFB	
NEVCO Energy Company, LLC	0.0154	24-hour avg	CFB	10/24/04 Permit
AES Beaver Valley	0.020	3-hour avg	CFB	11/21/01 Permit
ADM Company	0.025	3-hour avg	CFB	12/24/98 Permit
ADM Company	0.030	3-hour avg	CFB	6/30/98 Permit

Step 4 - Evaluate Economics, Energy and Additional Environmental Impacts

Economics

The White Pine Energy Station has a proposed generating capacity of 530 MW, per unit. The 300 MW CFB boilers at JEA Northside are currently the largest operating CFB boilers. Unlike PC boilers, CFB boilers have not been scaled up to the 530 MW capacity proposed for the White Pine Energy Station. Thus, steam generation capacities greater than 300 MW require the use of multiple CFB boilers to generate the steam flows required. The use of multiple boilers to achieve a given steam flow is more costly relative to utilizing a single boiler to generate the same steam flow due to the increased physical size of the facility, the incremental ancillary equipment to support two boilers, and the incremental staff to operate and maintain the second boiler.

The advantage of a CFB boiler is its ability to consume fuels not typically utilized in a PC boiler. These fuels are characterized by a high ash or moisture content, low heating value, and low volatile content and thus are lower cost on a $/MMBtu basis at the fuel source. However, transportation cost is a critical consideration in determining the fuel source and, in the case of using lower value fuels, transportation distances exceeding 50 to 100 miles often removes any economic benefit of burning the lower value fuel relative to coal. Long-term availability of these lower value fuels is also a consideration since a facility's economics will be severely impacted if the fuel source is no longer available in future years and higher cost fuels must be substituted. Therefore, most facilities equipped with a CFB boiler are located near one or more potential fuel sources to maximize the economic benefit of using the low value fuel and reduce the risk of fuel becoming unavailable.

A report prepared by Sargent & Lundy estimates both construction and comparative busbar generating cost estimates for CFB and PC technology for a generic, green-field 800 MW project to be located in Texas. CFB construction costs estimated at more an 15% higher and CFB busbar generating costs were estimated at more than 10% higher than a PC plant as shown in Tables 13.6 and 13.7 below.[2]

Table 3.6 – Comparison of PC and CFB Construction Costs for PRB Coal

	PC	**CFB**
Total project cost, $MM	$1,341	$1,541
$/kW overall project costs	$1,673	$1,927
Differences, $/kW	Base	15.2%

Table 13.7 – Comparison of PC and CFB Busbar Generating Costs for PRB Coal

	Levelized $/MWh Over Thirty Years, From 2009	
	PC	**CFB**
Total $/MWh	$51.09	$56.19

[2] Sargent & Lundy, LLC, "New Coal Generation Technology Assessment Study." November 2005

Differences, Percent	Base	10.0%
Differences, $/MWh	Base	$5.10

Assuming a multiple unit CFB facility would be $254/kW more expensive than a single unit PC facility of a similar overall capacity, and assuming that the lowest demonstrated emission limits of CFB facilities stated above, the incremental removal costs for SO_2 and filterable PM_{10} emissions were found to be $94,207/ton and $1,030,000/ton, respectively. Total NO_x emissions from a CFB facility, on a tons per year basis, will be slightly higher than a similarly sized PC facility because the heat rate is higher and more fuel will be burned to produce the same amount of electricity.

Energy and Additional Environmental Impacts

A facility equipped with a CFB will have a lower overall efficiency than a comparably sized PC unit due to a greater auxiliary power consumption of a CFB unit. Therefore, more fuel will have to be burned to produce the same amount of electricity, potentially leading to greater annual emissions.

Step 5 - Select Technology

CFB boiler technology is a mature technology that is commercially available from multiple suppliers. Application of a CFB boiler is principally driven by the steam generation capacity required and the fuel to be consumed. A single CFB boiler is limited in capacity to approximately 300 MW; greater capacities would require multiple boilers. In contrast, a single PC boiler can be furnished with a capacity up to approximately 1,000 MW. Emissions from a facility equipped with a PC boiler, SCR, and FGD system will be comparable to a facility equipped with a CFB boiler, SNCR, and FGD system when measured on a heat input basis. The true advantage of a CFB boiler is that it can utilize fuels not typically suited for combustion in a PC boiler.

For the White Pine Energy Station, a CFB boiler has not been selected due to the increased cost of installing two CFB boilers per PC boiler to meet the required capacity of the Facility, and the lack of fuels of sufficient volume and within reasonable distance from the facility to provide any economic advantage, and the high economic penalty for potentially reduced PM_{10} and SO_2 emissions.